

# Effects of Freshwater Biofilms On Flow Over Rough Surfaces

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This paper presents results from a research project investigating the effects of freshwater biofilms on flow over rough surfaces such as aged concrete open channels. Biofilms may be any combination of bacteria, algae, fungi, and invertebrate organisms. Unwanted biofilms are usually termed biofouling.

The basic problem of biofouling is the resulting change in wall roughness, which can vary widely, and can increase headloss and reduce flow carrying capacity. Biofouling has been widely identified to be a significant problem (Minkus, 1954; Bland, Bayley *et al.*, 1975; Brett, 1980; Picologlou, Zelter *et al.*, 1980).

Measurements were initially undertaken on a smooth acrylic plate and a clean artificially roughened plate to provide baseline information. The experimental program then involved the rough plate being deployed in a large open channel, with an approximate flow speed of 1 m/s, and allowed to have a biofilm grow and develop. The rough plate was retrieved after a period of 5 months and had mostly a filamentous type biofilm growth. Measurements were completed in the laboratory and the plate was then redeployed in the field. After an additional 4 months the plate was retrieved again and had mostly a low-form gelatinous type of biofilm.

The plates used in the present study were sized 597 mm wide by 997 mm long to fit in a closed loop, recirculating water tunnel built specifically for the research project. More information on the water tunnel can be obtained from (Barton, 2006). Incorporated into the water tunnel was a working section where measurements took place. The flow area for the working section measured 200 mm tall and 600 mm wide providing a flow velocity of between 0.3 m/s and 2 m/s.

Table 1 summarises the results of the boundary layer mean velocity profiles measured at a distance of 865 mm downstream of the leading edge of the test plate. The velocities were obtained by using a 1 mm outside diameter Pitot probe and static wall pressure.

Table 1: Summary of boundary layer parameters at 865mm from leading edge of plate.

Test Plate	U (m/s)	$\delta$ (mm)	$\delta^*$ (mm)	$\theta$ (mm)	$u^+$ (m/s)	$c_f$	H	$Re_{xPlate}$	$Re_{\delta^*}$	$Re_\theta$	$k_s$ (mm)
Smooth Acrylic Plate	1.03	43.89	5.27	4.27	0.0434	0.0035	1.24	1.22E+06	6.45E+03	5.22E+03	-
	1.59	37.64	4.51	3.66	0.0645	0.0033	1.23	1.88E+06	8.50E+03	6.90E+03	-
	1.93	37.62	4.49	3.66	0.0759	0.0031	1.23	2.28E+06	1.03E+04	8.36E+03	-
Rough Plate Clean	1.06	38.22	7.01	4.55	0.0598	0.0064	1.54	1.24E+06	8.73E+03	5.67E+03	1.96
	1.63	38.67	7.05	4.60	0.0868	0.0057	1.53	1.74E+06	1.23E+04	8.01E+03	1.30
	1.98	37.92	6.90	4.51	0.1082	0.0060	1.53	2.11E+06	1.46E+04	9.54E+03	1.44
Rough Plate with Filamentous Biofilm	1.05	37.55	6.64	4.47	0.0678	0.0084	1.49	1.18E+06	7.87E+03	5.30E+03	2.71
	1.61	36.86	6.57	4.39	0.0932	0.0067	1.50	1.82E+06	1.20E+04	8.00E+03	1.75
	1.96	34.99	6.23	4.17	0.1140	0.0067	1.50	2.21E+06	1.38E+04	9.24E+03	1.50
Rough Plate with Low-Form Gelatinous Biofilm	1.02	34.04	6.13	4.05	0.0630	0.0077	1.51	1.15E+06	7.04E+03	4.66E+03	2.93
	1.56	33.86	5.91	4.03	0.0912	0.0068	1.47	1.76E+06	1.04E+04	7.11E+03	2.10
	1.91	32.66	5.84	3.89	0.1027	0.0058	1.50	2.15E+06	1.26E+04	8.37E+03	1.42

Boundary layer measurements were made at Reynolds numbers (based on plate length) of approximately  $1.2 \times 10^6$ ,  $1.8 \times 10^6$  and  $2.2 \times 10^6$  for each plate. The logarithmic law of the wall is shown on each plot (Figure 1), and the  $1/7^{th}$  power law (smooth acrylic plate) and  $1/5^{th}$  power law (clean rough plate) are also shown for comparison purposes. Note the downward shift in the velocity profile (the roughness function,  $\Delta u^+$ ), for the rough plate (clean and with biofilm) from the smooth acrylic plate results, which is the velocity decrement due to the increase in wall roughness.

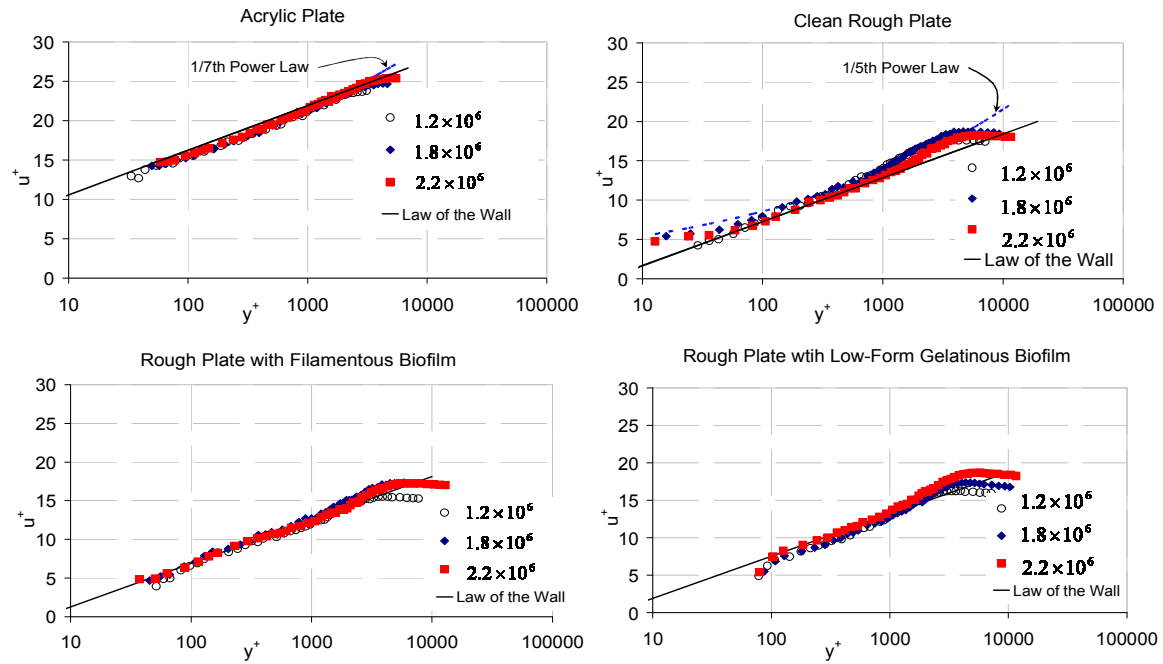


Figure 1: Boundary layer mean velocity profiles.

The test plate arrangement in the water tunnel was attached to a one-dimensional force balance to allow the measurement of total drag. Results for the total drag measurements of the respective test plates are shown in Figure 2. Corrections were required to remove non drag related forces and to account for the fact that the boundary layer did not commence at the leading edge of the test plate. These corrections are described in Barton (2006). Drag was measured to be the least for the smooth acrylic plate, then incrementally greater for the clean rough plate, rough plate with low-form gelatinous biofilm and then the rough plate with the filamentous biofilm.

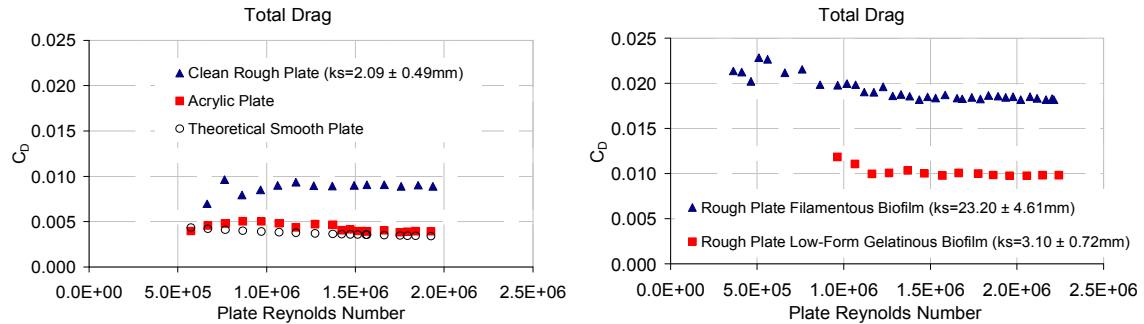


Figure 2: Total drag for test plates.

The change in local skin friction and total drag from the initially clean rough plate conditions are shown in Tables 2 and 3 respectively. Results show that both low-form gelatinous and filamentous type biofilms grown on a rough plate cause significantly greater drag than the clean rough plate. An increase in drag of 119% was measured for a filamentous biofilm grown on a rough plate compared to the rough plate in its clean condition.

Table 2: Change in local skin friction from clean rough plate conditions.

Approximate $Re_{Plate}$	Rough Plate Clean $c_f$	Rough Plate (Filamentous) $c_f$	Rough Plate (Gelatinous) $c_f$	Change in $c_f$ from Clean Condition	
				(Filamentous) %	(Gelatinous) %
$1.2 \times 10^6$	0.0064	0.0084	0.0077	31	20
$1.8 \times 10^6$	0.0057	0.0067	0.0068	17	20
$2.2 \times 10^6$	0.0060	0.0067	0.0058	12	-3

Table 3: Change in total drag from clean rough plate conditions.

Rough Plate Clean	Rough Plate (Filamentous)	Rough Plate (Gelatinous)	Change in $C_D$ from Clean Condition	
			(Filamentous)	(Gelatinous)
$C_D$	$C_D$	$C_D$	%	%
0.0088	0.0193	0.0102	119	15

Velocity defect profiles are shown in Figure 4 for  $Re_{plate} = 2.2 \times 10^6$ . The difference in velocity deficit can be clearly seen between the rough plate measurements and the smooth acrylic plate measurements.

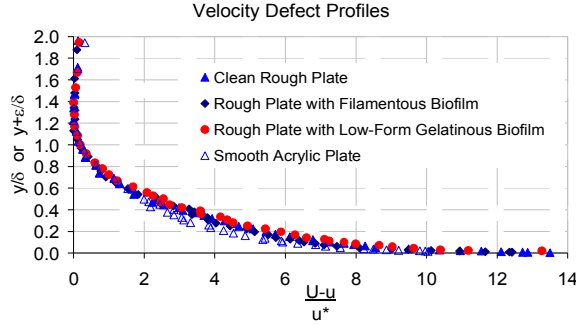


Figure 4: Velocity defect profiles.

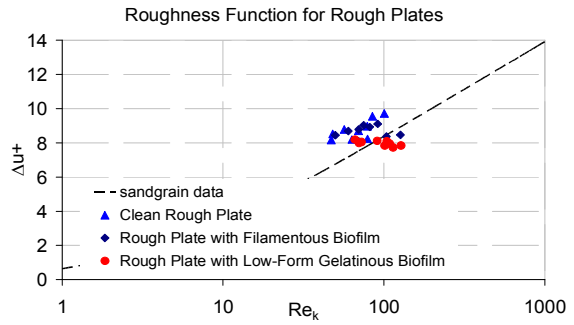


Figure 5: Plot of roughness functions for rough plate measurements.

Roughness information for the water tunnel measurements was derived from total drag measurements (which represent average values for the entire plate) and from boundary layer velocity profiles (which represents the flow condition along the plate longitudinal centerline).

Close range photography was used to characterise the physical surface of the biofilm on the the plates as this was non-invasive. Osborn, Bae *et al.* (2005) and Barton (2006) contain further information on the photogrammetric methods used. The physical roughness information derived from the photogrammetry is compared with the measured roughness from the water tunnel in Table 4. It is shown that the measured roughness using the water tunnel is greater than the mean surface roughness measured using photogrammetry, indicating that the roughness effect on the flow is larger than the measured roughness height.

Table 4: Comparison of roughness information.

Rough Plate Condition	Photogrammetry				Water Tunnel	
	Rt (mm)	Peak Count	Mean Surface Roughness (mm)	Mean Biofilm Thickness (mm)	Velocity Profile $k_s$ (mm)	Total Drag $k_s$ (mm)
Clean	1.69	14.30	0.68	-	1.57	2.09
Filamentous Biofilm	1.85	11.10	0.75	0.07	1.99	23.20
Gelatinous Biofilm	2.00	9.40	0.98	0.20	2.15	3.10

It is possible to relate  $\Delta u^+$  to the roughness character of the wall. Figure 5 presents a plot of the roughness functions derived from the mean velocity profiles. The mean surface roughness from the photogrammetry results were used to calculate  $Re_k$ . The data does not collapse well onto the sandgrain data (shown as a dashed line) based on a relation suggested by White (2006). A poor collapse of data was also experienced by Schultz and Swain (2000).

Of practical interest is the relationship between the measured wall shear velocity, and the roughness effect of the biofilm. Figure 6 shows that  $\frac{k_s}{\delta}$  increases with a decrease in  $u^*$ , supporting the concept of biofilm thinning under higher shear forces (Nikora, Goring *et al.*, 2002). The other general relationship is that  $\frac{k_s}{\delta}$  decreases as the flow Reynolds number decreases.

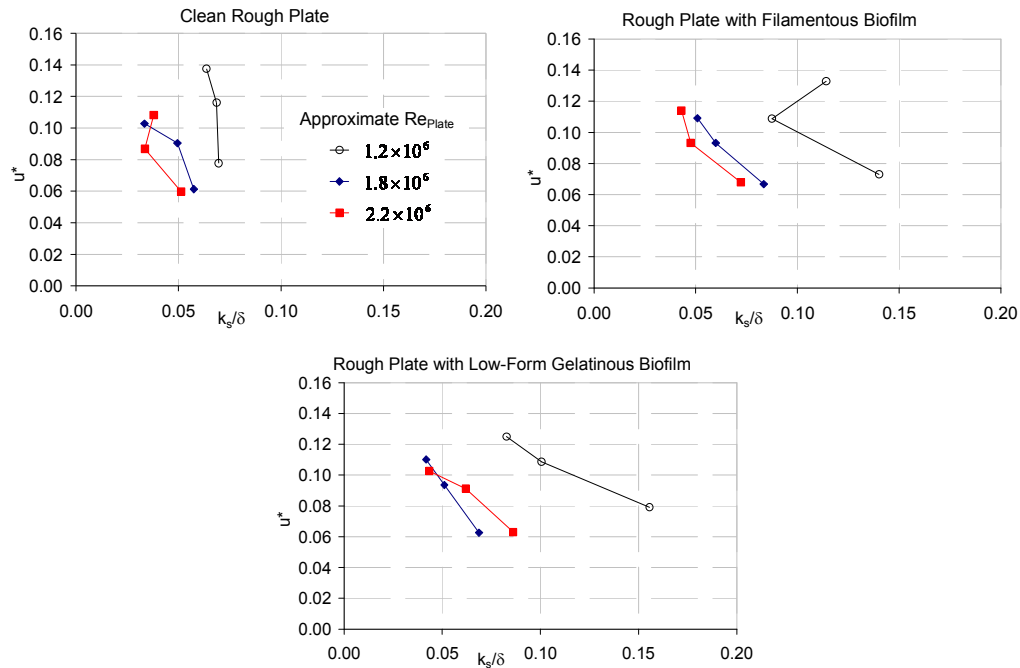


Figure 6: Biofilm roughness with different wall shear velocities

Results from this research have implications for the design, operation and maintenance of hydraulic conduits susceptible to biofouling, particularly conduits in hydroelectric schemes. Other applications could also be the better understanding of flow resistance in environmental flows.

#### Acknowledgements

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